

ENHANCING PHOSPHORUS SOLUBILITY FROM ROCK PHOSPHATE INTEGRATED WITH FARMYARD MANURE IN P-DEFICIENT SOIL

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The aim of this study was to assess the solubility of phosphorus from rock phosphate incubated with farmyard manure under laboratory condition. The treatments were factorial combination of three rates each of RP (0, 2, and 4 tons ha⁻¹) and farm yard manure (0, 10 and 20 tons ha⁻¹). These treatments were applied to 100 g soil contained in plastic vials with three replications. Seven such sets of 27 vials each were prepared to represent seven incubation periods namely 0, 15, 30, 45, 60, 75, and 90 days. The results showed that Olsen-P improved significantly with increasing rate of rock phosphate from 0 to 4 tons ha⁻¹ and that of farmyard manure from 0 to 20 tons ha⁻¹. Initial available P content of soil was 4.59 mg kg⁻¹ which enhanced up to 10.55 mg kg⁻¹ as a result of 90 days incubation. Addition of rock phosphate and farmyard manure increased it to maximum value of 23.03 mg kg⁻¹ with incorporation of rock phosphate at 4 tons ha⁻¹ and farmyard manure at 20 tons ha⁻¹. Thus, positive response of rock phosphate and farmyard manure was clearly evident on Olsen-P values due to enhancement of soil organic matter. It is concluded that there is potential for utilization of local rock phosphate by solubilising the P using farmyard manure. Soil incubation for the prolonged period of 90 days with rock phosphate and farmyard manure helped to enhance the solubility of P from rock phosphate. It is recommended that further experiments may be performed along with different bio-char, vermicompost, organic acids etc. which can help solubilise P from rock phosphate under field trials. For the first time, the feasibility of using agricultural fertilizer (manure) to increase the solubility of phosphorus from rock phosphate is experimentally substantiated. The practical value of this study is to achieve two effects simultaneously, namely, improving the fertility of agricultural lands depleted in phosphorus and utilizing agricultural fertilizer (manure).

Keywords: phosphorus solubility; rock phosphate; farmyard manure; incubation period.

ПІДВИЩЕННЯ РОЗЧИННОСТІ ФОСФОРУ З ФОСФОРИТУ, ІНТЕГРОВАНОГО З СІЛЬСЬКОГОСПОДАРСЬКИМ ГНОЕМ У ҐРУНТ ЗБІДНЕНИЙ ФОСФОР

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Метою цього дослідження є оцінка розчинності у ґрунті фосфору з фосфоритів, інкубованих з гноєм у лабораторних умовах. Обробка ґрунту була факторіальною комбінацією трьох показників фосфориту (0, 2 і 4 т/га) і сільськогосподарського гною (0, 10 і 20 т/га). Ця обробка була застосована до 100 г ґрунту, що міститься у пластикових флаконах з трьома повторностями. Було підготовлено сім таких наборів по 27 флаконів в кожному, щоб представити сім інкубаційних періодів, а саме 0, 15, 30, 45, 60, 75 і 90 днів. Результати показали, що Olsen-P значно покращився зі збільшенням норми фосфоритів з 0 до 4 т/га, а гною з ферми – з 0 до 20 т/га. Первісний доступний вміст фосфору в ґрунті становив 4,59 мг/кг, що збільшився до 10,55 мг/кг у результаті 90-денної інкубації. Додавання кам'яного фосфату і гною в фермерських господарствах збільшило вміст фосфору у ґрунті до максимального значення 23,03 мг/кг з урахуванням внесення 4 т/га фосфориту й 20 т/га сільськогосподарського гною. Таким чином, позитивний ефект сумісної дії фосфориту й сільськогосподарського гною був чітко видимим по значеннях Olsen-P через підвищення вмісту органічної речовини в ґрунті. Зроблено висновок про те, що існує потенціал для утилізації місцевого фосфориту шляхом розчинення фосфору з використанням сільськогосподарського гною. Інкубація ґрунту протягом 90 днів з фосфоритом й сільськогосподарським гноєм дала змогу підвищити розчинність фосфору з фосфоритів. Рекомендується проводити подальші експерименти з використанням біогумусу, органічних кислот тощо, які можуть допомогти розчинити фосфор з фосфоритів в польових умовах. Вперше експериментально обґрунтовано доцільність застосування сільськогосподарського гною для підвищення розчинності фосфору з фосфоритів. Практична цінність цього дослідження полягає в досягненні двох ефектів одночасно, а саме – поліпшення родючості земель сільськогосподарського призначення, збіднених фосфором, й утилізація сільськогосподарського гною.

Ключові слова: розчинність фосфору; фосфорит; сільськогосподарський гній; інкубаційний період

1. Problem statement and analysis of the recent researches and publications.

Increasing phosphatic fertilizer prices are contributing to the international food disaster that is beating the world poor.

Pakistan and are no exception to this. Similarly, phosphate fertilizers for Ukraine are also a huge problem, they are not enough. However, the search for domestic, alternative and affordable sources of phosphates is a very urgent task for

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Ukraine. It is predictable that ~5.7 billion/ha of arable soils international are poor in accessible phosphorus (P) [1], because of low absorption and/or low availability of soil P compounds [2], and un-able to endure greatest crop production. Although, the increase in fertilizer prices continues up slope for all the fertilizers, highest increase is noted in the price of phosphatic fertilizers, particularly during the past few years [3, 4, 5]. The price of DAP in Pakistan has increased from Rs. 993 in the year 2007-08 to Rs. 3,710 per bag of 50 kg in the year 2017-2018. In other words, the price of DAP has increased 3.53 times during the past ten years [6]. As fertilizer is the most important input, its availability at affordable prices is a necessity if crop production is to be increased on sustainable basis [7]. Indeed, rock phosphate (RP) is a basis source of P, but un-fortunately we lack reliable technology to make it appropriate for local soils that is alkaline [8]. However, in view of increasing energy cost and the limited reserves of rock phosphate, the prices of phosphatic fertilizers are not likely to reduce. Therefore, other options must be explored to come up with products and techniques for affordable use of local P sources. One of these options is to explore the possibilities of using locally available RP as a source of P for optimum crop production [9]. In addition, RP mines in Pakistan are in lowest quantity. However, the dominant phosphate reserves are located Khyber Pakhtunkhwa and Hazara division in the North East of the country has primary 3.25 and secondary 6.71 million tons RP of siliceous and dolomite in nature having 25.8 % P_2O_5 consists, moreover elevated MgO (up to 6 %) [10, 11]. In addition, significant phosphorite reserves have been identified in the Northwest region, Middle Transnistria, the Black Sea region and the Dnieper-Donetsk region. However, these domestic deposits can provide, when fully loaded, for production, about 700 thousand tons of 100 % P_2O_5 per year, which is about 45 % of the amount needed to load capacities for the production of phosphorus-containing fertilizers. Involvement in the production of phosphate raw materials with P_2O_5 less than 24 % is not economically feasible. Particular attention should be paid to the use of personal protective equipment during the application of phosphate fertilizers. Phosphorite flour adversely affects the skin, causing irritation, burns. With chronic exposure to the skin, dryness, burning, cracks, peeling, brittle nails appear. Studies have established that when phosphate fertilizers were applied to the soil with seeders in the tractor cabin, significant dust concentrations of powdered superphosphate from 100 to 372 mg/m³ were found. It should be noted that, when superphosphate was added to the soil, the content of sulphuric anhydride in the air ranged from 0.7 to 14.5 mg/m³ [12]. Consequently, number of agro-wastes (farmyard manure (FYM), poultry manure, chicken manure etc.) can be added to increase the solubility of solid rock phosphate. Pakistan has significant number of farm animals, which contribute approximately 50 % animal waste is not collected and the remaining is not utilized [13]. Soils of Pakistan are alluvial in nature with $CaCO_3 > 3.0$ % containing no native P. It has been reported that about 90 % soils of Pakistan are deficient in P [14]. Rock phosphate is a natural, cheap and clean compound but unfortunately it has low P percent and also its solubilisation is too slow to satisfy plant requirement. The direct addition of RP to be found highly effective in acidic soils with low pH which assist to mobilize the RP and enhance P bioavailability from soil to plant, but this approach is failure in alkaline and/or calcareous soils because of high pH [15, 16]. A significant number of literatures have reported the solubility and bio-availability P from rock phosphate might be affected due to influence of soil pH, particle size of RP, and quantity of P and Ca in soil pool [8, 17, 18]. To

overcome the problem, RP is integrated with organic materials (OM) namely, farm yard manure, poultry manure, compost and bio-char etc to bring P in to soluble form which can be taken up by the plant [19]. Moreover, the mobility of P improved with enhances in OM concentration in soil medium [20]. At the same time RP is principally tri-calcium phosphate with non-soluble P [21]. The augment in P mobility found through mixing of rock phosphate with organic additives was also investigated by [22]. Thus RP is being documented as another source of P for restoration P-deficient soils [23, 24], and to face the problem of increasing cost of P fertilizers. Application of local RP along with farm yard manure is found feasible and robust technology offers an alternative solution to the waning interest of farmers P deficient soils. This laboratory incubation study was performed to examine the solubility and hence the solubility of P from RP as a function of incubation period and farm yard manure. In view of the foregoing, this research, sought to investigate: (1) the influence of FYM on the solubility of P from rock phosphate, (2) quantify the available P from rock phosphate as a function of incubation period, and (3) appraise the effect of FYM and rock phosphate on soil organic matter.

2. Statement of the problem and its solution.

2.1 Materials and Methods.

Collection of soil and amendments. A surface soil (0 – 15 cm depth) in bulk was collected from Latif Experimental Farm Tandojam (25°43'5492" N, 68°54'4557" E), Sindh, Pakistan for the purpose. The collected samples were dried at normal temperature (23 °C) for 5 days, later on manually crushed and ground to pass through 2 mm sieve for laboratory incubation. The rock phosphate (RP) sample was collected from kakul mine Haripur Hazara places of Khyber Pakhtunkhwa, while the farm yard manure was taken from Dairy Farm of Sindh Agriculture University, Tandojam.

Experimental set-up. A laboratory incubation study was conducted at Soil Fertility Research Laboratory of Department of Soil Science to investigate the phosphorus availability from rock phosphate incubated with farm yard manure for different incubation periods. Three rates of each rock phosphate (0, 2, and 4 tons ha⁻¹) and farm yard manure (0, 10, and 20 tons ha⁻¹) were used to form 9 treatments: (T1) Un-amended control (RP 0 + FYM 0); (T2) RP 0 + FYM 10 tons ha⁻¹; (T3) RP 0 + FYM 20 tons ha⁻¹; (T4) RP 10 tons ha⁻¹ + FYM 0; (T5) RP 10 tons ha⁻¹ + FYM 10 tons ha⁻¹; (T6) RP 10 tons ha⁻¹ + FYM 20 tons ha⁻¹; (T7) RP 20 tons ha⁻¹ + FYM 0; (T8) RP 20 tons ha⁻¹ + FYM 10 tons ha⁻¹; (T9) 20 tons ha⁻¹ + FYM 20 tons ha⁻¹. These treatments were applied to 100 g soil contained in plastic vials and replicated three times in randomized complete block design. In this way seven sets (each of 27 vials) were prepared to represent seven incubation periods namely 0, 15, 30, 45, 60, 75, and 90 days. Soil was moistened to about 50 % field capacity, by adding 20 ml distilled water to each vial. These vials were covered with perforated plastic sheet to provide aerobic conditions, while conserving moisture. The weight of each vial was separately recorded as to form the basis for maintaining the moisture content of each treatment on daily basis during incubation. All the vials were maintained at 25 ± 1 °C in the incubator (Cooling Incubator Model LRH-25, HT Company, Ilford Ltd. UK) throughout the incubation period of 90 days. The set meant for zero days incubation period was prepared for analysis without undergoing incubation process. The other six sets of 27 vials, each were placed in the incubator. After incubation period of every 15 days, one set of 27 vials was removed from the incubator. The soil obtained after each incubation was air-dried by spreading over a plastic sheet, and preserved for P and organic matter analysis.

Analysis of soil and amendments. The soil used in this study was assessed for EC (Model HI 8033) and pH (Model WTW pH720) in 1:2 soil-water extract, soil texture by Bouyoucos Hydrometer method [25], and calcium carbonate by acid neutralization method [26]. The organic matter and available P in soil were determined before and after the incubation of soil. Organic matter was determined by Walkley-Black method [27]. While, available P in soil (before and after incubation) was extracted by [28], and the amount of P in the extract was determined by ascorbic acid colour development method [29], using spectrophotometer (Model ANA 75).

The total P content in FYM was tested by first digesting the sample in an acid mixture ($\text{HClO}_4 : \text{HNO}_3 - 1 : 5$), followed by P analysis by vanadomolybdo-phosphoric acid yellow colour method [30], using spectrophotometer. Organic matter and organic carbon in FYM was determined by loss on ignition method. Five grams FYM sample was taken in pre-weighed porcelain crucibles, which were kept in muffle furnace for 5 hours at 550 °C. After cooling the crucibles were weighed to determine the loss on ignition as followed by [31]. The P in RP was measured followed by [32]. Furthermore, grinded 0.1 g of RP was dissolved in HCL and left it for overnight then raised volume up to 100 ml. After that, 2 ml from aliquot was also raised to 100 ml. The 20 ml was taken from above solution and then 5 ml colour solution was added to determine the P by using spectrophotometer.

Statistical analysis. All the data was analyzed with using Excel 2013 and Statistics 8.01 program. Analysis of variance was carried out using 2 factor randomized complete block design (RCBD). The comparison of means was done by using Tukey's HSD range test. All graphs were made by using OriginPro. 16.

2.2. Results.

Soil properties. Some selected properties of the soil, used for the laboratory incubation experiment are presented in

Table 1. The particle size distribution showed that the soil contained 44.5 % sand, 30.5 % silt and 25 % clay and it was a loam in texture. The data further showed that the soil was medium alkaline in reaction having pH 7.58, non-saline ($< 2 \text{ dS m}^{-1}$) with EC 0.50 dS m^{-1} , moderately calcareous with 9.8 % CaCO_3 content, low in organic matter with 0.71 % organic matter and low in available P with 4.59 mg kg^{-1} Olsen-P.

Olsen-P in relation to rate of RP and FYM at 0, 15, 30, 45, 60, 75 and 90 days of incubation. Table 2 revealed that the soil used for this study was poor in available P, containing 4.59 mg kg^{-1} Olsen-P. The application of FYM or RP did not significantly improve the Olsen-P contents of soil at the time of their application to soil. The Olsen-P values ranged from the lowest value of 4.59 mg kg^{-1} in un-amended soil to maximum value of 8.90 mg kg^{-1} for the treatment receiving RP at 4 tons ha^{-1} .

Table 1 – Selected physicochemical parameters of the soil used for the incubation study. Mean $\pm$ standard deviation (n = 3)

Soil property	Value
Particle size distribution	
Sand, %	44.5
Silt, %	30.5
Clay	25
Textural Class	Loam
EC _{1:2} , dS m^{-1}	0.50 ± 0.2
pH _{1:2}	7.58 ± 0.1
Organic matter, %	0.71 ± 0.6
Lime CaCO_3 , %	9.8 ± 0.1
Olsen-P, mg kg^{-1}	4.59 ± 0.3

The data in Table 2 indicated that the soil used for this study was low in Olsen-P ($< 10 \text{ mg kg}^{-1}$) even after the application of RP and FYM at soil incubation for 15 days. The values ranged from the lowest value of 5.80 mg kg^{-1} in un-amended soil to greatest value of 9.14 mg kg^{-1} for the treatment receiving RP at 2 tons ha^{-1} and FYM at 20 tons ha^{-1} .

Table 2 – Olsen-P in soil in relation to application rates of rock phosphate and farmyard manure at 0, 15, 30, 45, 60, 75 and 90 days of incubation periods

Treatments	Incubation period						
	0 day	15 days	30 days	45 days	60 days	75 days	90 days
T1	4.59 a	5.80 a	7.80 b	6.88 b	9.11 b	7.41 e	10.55 b
T2	5.86 a	6.78 a	8.91 ab	12.91 ab	11.85 ab	13.53 bcd	13.90 ab
T3	7.05 a	7.26 a	10.89 a	13.58 ab	12.60 ab	16.9 ab	21.57 ab
T4	4.69 a	7.17 a	8.80 ab	11.16 ab	11.86 ab	9.603 de	12.98 ab
T5	5.35 a	7.86 a	10.23 ab	12.10 ab	12.46 ab	14.83 bc	15.48 ab
T6	6.44 a	9.14 a	9.35 ab	13.84 ab	13.64 ab	17.20 ab	22.19 a
T7	5.10 a	7.37 a	7.92 b	12.60 ab	12.16 ab	10.95 cde	18.53 ab
T8	5.83 a	7.57 a	9.68 ab	14.98 a	13.34 ab	15.87 ab	20.84 ab
T9	8.90 a	8.45 a	10.34 ab	15.19 a	15.72 a	20.35 a	23.03 a

Means sharing similar letter in a row or in a column are statistically non-significant ($p > 0.05$)

However, the addition of FYM or RP did not significantly improve the Olsen-P contents of soil over the untreated soil. The obtained data in Table 2 showed improvement in Olsen-P values as a result of increase in incubation time. Overall average of the data taken over RP and FYM rates showed that Olsen-P had increased to 9.32 mg kg^{-1} at 30 days of incubation as against 5.98 recorded at the start of incubation. Olsen-P content of un-amended soil was 7.80 mg kg^{-1} at 30 days of incubation which increased significantly to 10.89 mg kg^{-1} with addition of FYM at

20 tons ha^{-1} . This trend was observed even when RP was applied at 2 or 4 tons ha^{-1} . However, the application of RP alone did not significantly improve the Olsen-P contents of soil. It is clearly evidenced from the data in Table 2 that increase in period of incubation is contributing to increase in Olsen-P values. Overall mean of the Olsen-P values was observed to be 12.58 mg kg^{-1} at 45 days of incubation compared to 5.98 mg kg^{-1} at zero days of incubation. It is also significant to note that Olsen-P content of un-amended soil registered an increase from 4.59 mg kg^{-1} at zero days of

incubation to 6.88 mg kg^{-1} at 45 days of incubation. This corresponds to about 50 % increase in Olsen-P without addition of RP or FYM. With addition of FYM, Olsen-P increased further to maximum value of 13.58 mg kg^{-1} . Thus, application of FYM significantly improved the Olsen-P contents of soil irrespective of the rate of RP applied. Further, it was noted the application of RP alone did not significantly improve the Olsen-P contents of soil. The Olsen-P values ranged from the lowest value of 6.88 mg kg^{-1} un-amended soil to maximum value of 15.19 mg kg^{-1} for the treatment receiving RP at 4 tons ha^{-1} and FYM at 20 tons ha^{-1} .

The obtained data in Table 2 showed that the Olsen-P content of un-amended soil was 9.11 mg kg^{-1} . The application of FYM or RP evidently enhanced the Olsen-P contents of soil with the values ranging from minimum value of 9.11 mg kg^{-1} in un-amended soil to highest value of 15.72 mg kg^{-1} in the treatment receiving RP at 4 tons ha^{-1} and FYM at 20 tons ha^{-1} . On an average, the addition of FYM at 20 tons ha^{-1} improved Olsen-P values from 11.04 to 13.99 mg kg^{-1} . In case of RP application (4 tons ha^{-1}), the values increased from 11.19 to 13.74 mg kg^{-1} . The data in Table 2 showed that Olsen-P contents of un-amended soil had increased from 4.59 to 7.41 mg kg^{-1} over a period of 75 days. The application of FYM or RP improved it further and significantly increased the Olsen-P contents of soil to highest value of 20.35 mg kg^{-1} in the treatment receiving RP at 4 tons ha^{-1} and FYM at 20 tons ha^{-1} . Averaged by the rate of FYM applied, Olsen-P contents increased from 9.31 mg kg^{-1} at zero FYM to 18.15 mg kg^{-1} at 20 tons ha^{-1} FYM. Corresponding values for RP rates were 12.61 at zero RP to 20.35 mg kg^{-1} at 4 tons ha^{-1} RP. Overall average for Olsen-P at 75 days of incubation was 14.07 mg kg^{-1} . The application of FYM as well as RP dramatically enhanced the Olsen-P contents of soil Table 2. The Olsen-P level ranged from the minimum level of 10.55 mg kg^{-1} in un-amended soil to greatest quantity of 23.03 mg kg^{-1} in the treatment receiving RP at 4 tons ha^{-1} and FYM at 20 tons ha^{-1} . It was noted that addition of either 2 tons ha^{-1} RP or 10 tons ha^{-1} FYM was not effective in improving Olsen-P content of soil even at 90 days of incubation. It required addition of 4 tons ha^{-1} RP or 20 tons ha^{-1} FYM or both to significantly improve the Olsen-P content of soil. However, the interactions between RP and FYM were also statistically non-significant.

Olsen-P in relation to the period of incubation 0 to 90 days. Figure 1 shows the pooled Olsen-P data with respect to the period of incubation up to 90 days.

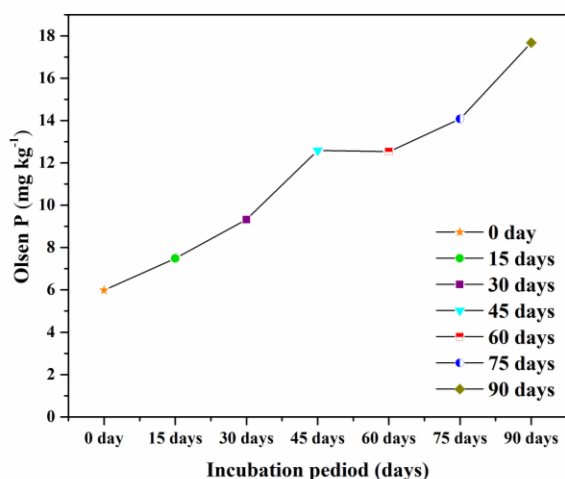


Figure 1 – Olsen-P in soil in relation to application rates of rock phosphate and farmyard manure at 0 to 90 days of incubation periods

Averaged over RP and FYM rates, the Olsen-P value was 5.98 mg kg^{-1} at zero day of incubation. Each incubation period of 15 days resulting an enhance in Olsen-P values in soil and maximum value of 17.67 mg kg^{-1} was achieved at 90 days of incubation. This corresponds to almost three-fold increase in Olsen-P as a result of incubation for 90 days. Further, it was noted from the data that there is potential for further increase in Olsen-P if the incubation period is extended beyond 90 days.

Organic matter in soil in relation to RP and FYM at 0, 15, 30, 45, 60, 75 and 90 days of incubation. The data in Table 3 showed that the soil used for this study was low in organic matter (0.71 %). The application of RP showed significant increase in the organic matter. For the means taken over FYM rates, the values were 0.81, 0.91, and 0.97 % at RP rates 0, 2, and 4 tons ha^{-1} , respectively. In case of FYM, the average values were 0.79, 0.93, and 0.98 % at FYM rates 0, 10, 20 tons ha^{-1} . On overall basis, the organic matter values ranged from the lowest value of 0.71 in un-amended soil to maximum value of 1.03 for the treatment receiving RP at 2 tons ha^{-1} and FYM at 20 tons ha^{-1} . The data in Table 3 found that addition of RP did not significantly influence the soil organic matter level. For the treatments not receiving any FYM, the soil organic matter ranged from 0.66 to 0.74 % (mean 0.73 %) at different rates of RP application. When means were taken over the FYM rates, the values ranged from 0.91 to 1.19 % for the three RP rates. As anticipated, the addition of FYM significantly enhanced the organic matter contents of soil with mean values ranging from 0.73 % where no FYM was applied to 1.39 % with application of FYM at 20 tons ha^{-1} .

It was observed that, on an average, the soil organic matter contents slightly increased when the incubation period was increased from 15 to 30 days. Table 3 clearly showed that the soil organic matter contents were only affected by the rate of FYM application. Where no FYM was applied, the values varied within a narrow range from 0.74 to 0.89 % for the RP treatments, and averaged to 0.83 %. With application of FYM, the average value increased from 0.83 % to 1.11 %, at 10 tons ha^{-1} FYM and to 1.21 % at 20 tons ha^{-1} FYM. Each rate of FYM produced significant augment in the OM concentration. Overall, the OM contents ranged from the lowest value of 0.74 % where no FYM was applied to 1.30 % where FYM was applied at 20 tons ha^{-1} . The data in Table 3 presents the organic matter data at 45 days of incubation. It essentially follows the same trend as was noted for 15 and 30 days after incubation. However, the soil organic matter values were noted to be increasing with the passage of time, even for the treatments receiving no RP or FYM. The soil from un-amended control treatment contained 0.91 % organic matter. There was no increase with the addition of RP but the addition of FYM significantly enhanced the organic matter contents of soil, on an average, to 1.14 % at 10 tons ha^{-1} FYM and to 1.47 % at 20 tons ha^{-1} FYM. There was no interaction between RP and FYM rates.

The OM concentration of the un-amended soil was 0.97 % as against 0.71 % at the start of the study Table 3. Application of RP appeared to contribute to increase in organic matter levels but the treatment differences were statistically non-significant. This was not the case with FYM application which significantly improved the organic matter contents of soil. Averaged by FYM rates, the values were 1.17 % for the treatments not receiving FYM, 1.52 % at 10 tons ha^{-1} and 1.48 % at 20 tons ha^{-1} . Highest value of 1.64 % organic matter was noted for the treatment receiving RP at 4 tons ha^{-1} and FYM at 20 tons ha^{-1} . The data in Table 3 showed further improvement in organic matter content of un-amended soil with increase in incubation period to 75 days. The value was 0.71 % at the start of the incubation, which increased to 0.97 % at 60 days and to 1.05 % at 75 days after incubation. It was noted that the organic matter appeared to increase further with the addition of RP but the treatment differences were found to be non-significant.

Table 3 – Organic matter in soil in relation to application rates of rock phosphate and farm yard manure at 0, 15, 30, 45, 60, 75 and 90 days of incubation periods

Treatments	Incubation period						
	0 day	15 days	30 days	45 days	60 days	75 days	90 days
T1	0.71 b	0.78 a	0.84 a	0.91 a	0.97 a	1.05 a	1.09 bc
T2	0.85 ab	0.86 a	1.05 a	0.92 a	1.49 a	1.63 a	1.63 abc
T3	0.87 a	1.09 a	1.16 a	1.43 a	1.28 a	1.84 a	1.70 a
T4	0.75 b	0.66 a	0.89 a	0.87 a	1.35 a	1.43 a	1.59 c
T5	0.95 ab	1.05 a	1.09 a	1.10 a	1.54 a	1.32 a	1.77 ab
T6	1.03 a	1.85 a	1.17 a	1.51 a	1.50 a	1.70 a	1.92 abc
T7	0.91 b	0.74 a	0.74 a	0.93 a	1.18 a	1.44 a	1.58 bc
T8	0.97 ab	0.96 a	1.18 a	1.40 a	1.51 a	1.46 a	1.76 abc
T9	1.02 ab	1.21 a	1.30 a	1.45 a	1.64 a	1.80 a	1.95 abc

Means sharing similar letter in a row or in a column are statistically non-significant ($p > 0.05$)

The application of FYM, however, significantly improved the organic matter contents. When averaged by FYM rates, the values were 1.31, 1.47 and 1.78 % at 0, 10 and 20 tons ha^{-1} , respectively. On overall basis, highest value of 1.84 % organic matter was obtained with addition of 20 tons ha^{-1} FYM. Further, it was noted that the interactions between RP and FYM rates statistically significant, reflecting differential effect of RP at various rates of FYM. With no FYM application, the organic matter values showed increasing trend with increase in the RP rate while the trend reversed when FYM was applied at 10 tons ha^{-1} and remained more or less unaffected at 20 tons ha^{-1} FYM. At the end of the incubation period i.e. 90 days, the organic matter content of un-amended soil registered an increase from initial value of 0.71 to 1.09 %. It is clearly noticeable from the data in Table 3 also reflected an evidently improve in soil organic matter with the addition of rock phosphate. On an average, the values were 1.48, 1.76, and 1.77 % at RP rates 0, 2, and 4 tons ha^{-1} . Similarly, the application of FYM also significantly improves the organic matter contents of soil, with values ranging from 1.42 % with no FYM application to 1.86 % with the addition of 20 tons ha^{-1} FYM. On overall basis, the highest value of 1.95 % organic matter was recorded for the treatment receiving RP at 4 tons ha^{-1} and FYM at 20 tons ha^{-1} .

Organic matter in relation to the period of incubation 0 to 90 days. The data in Figure 2 presents the pooled organic matter data, averaged over RP and FYM rates, as a function of the period of incubation up to 90 days. The organic matter content of un-amended soil was 0.89 % at zero day of incubation. Each incubation period of 15 days resulted in increase in organic matter and maximum value of 1.66 was achieved at 90 days of incubation. This corresponds to almost two-fold increase in OM as a result of incubation for 90 days.

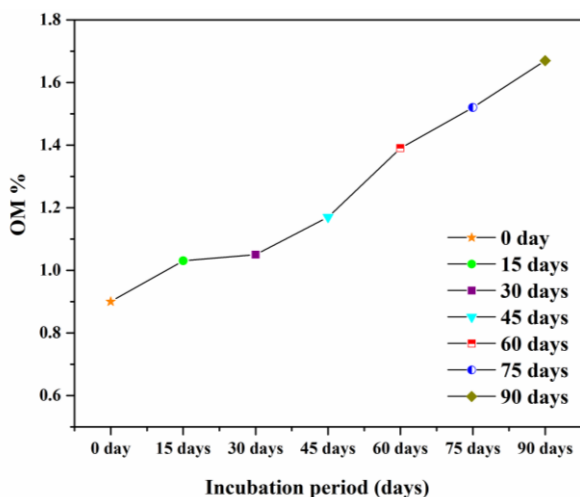


Figure 2 – Organic matter in soil in relation to rock phosphate and farmyard manure at 0 to 90 days of incubation periods

2.3. Discussion.

Availability of P and its application at affordable price is a major issue in agriculture. Yet the unbalanced use of P fertilizers can either reduce the nutrient application or may lead to fixation of P causing environmental pollution [1]. The application of P by applying a cheaper source of P such as rock phosphate can reduce the cost of chemical P fertilizers. The enhance in P fertilizer lost available in market has developed attention in the use of RP, a sedimentary rock, containing almost no water soluble P. Many studies have been carried out to enhance the solubility of P from RP using a variety of techniques and available materials such as FYM, poultry manure, etc. Rock phosphate and FYM are both locally available in the country and therefore desirable to use as alternate sources for supply of P at cheaper rates [6, 33, 34]. The FYM used in this study had organic matter content of 30 %, organic carbon 70 % and 0.17 % of total P. In case of rock phosphate, total P content was 7.46 % (17.08 % P_2O_5). The addition of rock phosphate up to 4 tons ha^{-1} improved the solubility of phosphorus (Olsen-P) in soil from initial value of 4.59 to 18.53 $mg\ kg^{-1}$ when incubated from 0 to 90 days. Each rate of RP contributed to increase in available P. Similarly, the application of FYM also improved P quantity of soil with each rate of its application to 13.90 $mg\ kg^{-1}$ at 10 tons ha^{-1} and to 21.57 $mg\ kg^{-1}$ at 20 tons ha^{-1} through incubation period of 90 days. Thus, soil incubation with RP and FYM resulted in increasing Olsen-P values over time. Averaged over RP and FYM rates, the Olsen-P value was 5.98 $mg\ kg^{-1}$ at zero day of incubation. Each incubation period of 15 days resulted in increase in Olsen-P values in soil and maximum value of 17.67 $mg\ kg^{-1}$ was achieved at 90 days of incubation. This was equivalent to almost three-fold increase in Olsen-P as a result of incubation for 90 days. The incorporation of FYM up to 20 tons ha^{-1} enhanced the organic matter in soil from initial percentage 0.71 to 1.58 % after 90 days to incubation period. In similar trend, the application of FYM also enhanced organic matter percentage of soil with each rate of its application to 1.76 % at 10 tons ha^{-1} and 1.95 % at 20 tons ha^{-1} after incubation period of 90 days. Consequently, soil incubation with RP and FYM resulted in increasing organic matter values over time. Averaged over RP and FYM rates, the organic matter was obtained by 0.90 % at zero day of incubation. Each incubation period of 15 days resulted in increase in OM percentage in soil, and maximum value of 1.67 % was received at 90 days of incubation. This was equivalent to almost two-fold increase in OM subsequently incubation period for 90 days.

The findings of the present research indicate similarity with the previous research work by [35], who revealed that P solubility from indigenous rock phosphate sources increased with the incubation period up to 75 days only. In a similar study [36], compared different rock phosphates with superphosphate in a laboratory incubation study in slightly

alkaline soils (pH 7.5). Meanwhile, P solubility from these sources enhanced with the P addition doses from 60 to 180 kg ha⁻¹ P₂O₅, and with the incubation period up to 75 days. Addition of FYM at the rate of 60 tons ha⁻¹ indicated little influence on the solubility of P from the RP. The results of this study could also be seen in the light of the works investigated by [37, 33]. Furthermore, Zayed and Abdel-Motaal, [38] revealed that phosphorus availability in sandy soil was significantly increased with addition of rice straw made compost enriched with RP and assisted with *Aspergillus niger*, *Trichoderma viride* and/or FYM. Besides, Garg and Bahl, 2008 [39] stated that the maximum quantity of Olsen-P was in poultry manure as soil amendment. The work reported by Osivand et al. [40], also supports the results of this study. They conducted a laboratory incubation study experiment for 90 days to progress the solubility of P from low-quality RP by preparing RP-enriched compost (RP-compost). Olsen-P improved during the 90-d incubation period and was peak in straw compost followed by other treatments. The results obtained were also in accordance with the conclusion made by Al-oud [34], conducted a laboratory incubation study and found that the mobility of P from RP was improved by rising incubation period up to 90 days regardless of the rate of amended RP. In contrast the solubility and /or availability of RP were increased by increasing the rate of applied elemental sulphur and/or organic manure. Another study conducted by Yadav et al. [8] who reported that P availability in soil and absorption by wheat crop was noticed with incorporation of RP and organic compost. Rahman et al. [11] suggested that solid rock

phosphate with 100 % acidulated as amendment significantly promoted wheat crop yield and P use efficiency in calcareous soil. Poblete-Grant et al. [41] stated that a blend of poultry manure and rock phosphate has positive effects in terms of soil P availability.

Conclusion and recommendations.

It is concluded that there is potential for utilization of local rock phosphate by solubilising P using FYM. Soil incubation for prolonged period of 90 days with rock phosphate and FYM helped increase the solubility of P from RP. Thus, positive effect of rock phosphate along with FYM on Olsen-P highlights the significance of rock phosphate along with FYM for supply of available P. On the basis this finding should be conformed in the long term field conditions on different plant genotypes. These feasible amendments should be focus on P fractionation, microbial activity, enzymes activity, and physical/chemical properties.

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Conflicts of Interest.

The authors declare no conflicts of interest in this research.

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ПОВЫШЕНИЕ РАСТВОРИМОСТИ ФОСФОРА ИЗ ФОСФОРИТА, ИНТЕГРИРОВАННОГО С СЕЛЬСКОХОЗЯЙСТВЕННЫМ НАВОЗОМ, В ПОЧВУ, ОБЕДНЕННУЮ ФОСФОРОМ

Целью этого исследования является оценка растворимости в грунте фосфора из фосфоритов, инкубированных с навозом в лабораторных условиях. Обработка грунта была факториальной комбинацией трех показателей фосфоритов (0, 2 и 4 т/га) и сельскохозяйственного навоза (0, 10 и 20 т/га). Эта обработка была применена к 100 г почвы, содержащейся в пластиковых флаконах с тремя повторностями. Было подготовлено семь таких наборов по 27 флаконов в каждом, чтобы представить семь инкубационных периодов, а именно 0, 15, 30, 45, 60, 75 и 90 дней. Результаты показали, что Olsen-P значительно улучшился с увеличением нормы фосфоритов с 0 до 4 т/га, а сельскохозяйственного навоза – с 0 до 20 т/га. Первоначальное доступное содержание фосфора в почве составляло 4,59 мг/кг, а увеличилось до 10,55 мг/кг в результате 90-дневной инкубации. Добавление фосфорита и сельскохозяйственного навоза увеличило содержание фосфора в грунте до максимального значения 23,03 мг/кг с учетом внесения 4 т/га фосфорита и 20 т/га сельскохозяйственного навоза. Таким образом, положительный эффект совместного действия фосфорита и сельскохозяйственного навоза был отчетливо виден по значениям Olsen-P вследствие повышения содержания органического вещества в почве. Сделан вывод о том, что существует потенциал для утилизации местного фосфорита путем растворения фосфора с использованием сельскохозяйственного навоза. Инкубация почвы в течение 90 дней с фосфоритом и сельскохозяйственным навозом позволила повысить растворимость фосфора из фосфоритов. Рекомендуется проводить дальнейшие эксперименты с использованием различных видов биоуглей, биогумуса, органических кислот и т. д., которые могут помочь растворить фосфор из фосфоритов в полевых условиях. Впервые экспериментально обоснована целесообразность применения сельскохозяйственного навоза для повышения растворимости фосфора из фосфорита. Практическая ценность данного исследования состоит в достижении двух эффектов одновременно, а именно – улучшения плодородия земель сельскохозяйственного назначения, обедненных фосфором, и утилизация сельскохозяйственного навоза.

Ключевые слова: растворимость фосфора; фосфорит; сельскохозяйственный навоз; инкубационный период.